Three-Dimensional Adjustment of Stratified Flow Over a Sloping Bottom

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LONG-TERM GOALS

Our ultimate goal is to understand the dynamics of strong, narrow ocean currents that persist for hundreds or thousands of kilometers, despite being in contact with the (frictional) bottom.

SCIENTIFIC OBJECTIVES

Our immediate objective is to understand how vertical mixing and advection within the bottom boundary layer influence the three-dimensional structure, evolution, and dynamics of both the bottom boundary layer and the overlying (interior) flow.

APPROACH

Our study is based on our idealized semi-analytical model of the adjustment of a stratified flow over a sloping bottom (Chapman and Lentz, 1997) which suggests that an equilibrium can be achieved in which both the bottom boundary layer and the overlying current adjust through feedback mechanisms such that the bottom stress is reduced to zero everywhere. The current can then continue unimpeded by bottom friction. Our approach consists of three parts: (1) we are using a primitive equation numerical model to elucidate results from our idealized model and to determine the limitations of our idealized model; (2) we are analyzing existing observations to determine whether the structure of the bottom boundary layer and the flow field above are consistent with our idealized model; and (3) we are attempting to extend the idealized model to more realistic conditions.

WORK COMPLETED

We have made progress on the first two parts of the work. We have configured the numerical model (SPEM5.1) to examine the adjustment of a narrow along-isobath current over a uniformly sloping bottom. We have made numerous calculations using a variety of stratifications, bottom slopes, bottom frictions and vertical mixing schemes to compare with the idealized model predictions.

We have collected and analyzed existing, long-term, moored current observations from a sequence of field programs over the northern California shelf (Coastal Ocean Dynamics Experiment, CODE; Shelf Mixed Layer Experiment, SMILE; Sediment Transport Events on Shelves and Slopes, STRESS;

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Northern California Coastal Circulation Study, NCCCS) to determine the vertical structure and dynamics of the low frequency flow.

RESULTS

For the parameter ranges we have considered, the structure of the bottom boundary layer and the overlying flow far downstream from the inflow in the numerical model are qualitatively similar to the idealized model (Figure 1). There are, however, some important quantitative differences. For example, in the numerical model the structure of the boundary layer is asymmetric and the interior velocity is weaker. Perhaps more important is that the numerical model does not produce the vertical isopycnals of the idealized model on the deep side of the current. This appears to be caused by a strong convergence in the bottom boundary layer that pumps fluid into the interior above the bottom boundary layer, thereby introducing vertical shear into the interior flow. The detailed dynamics of this flow are still under investigation.

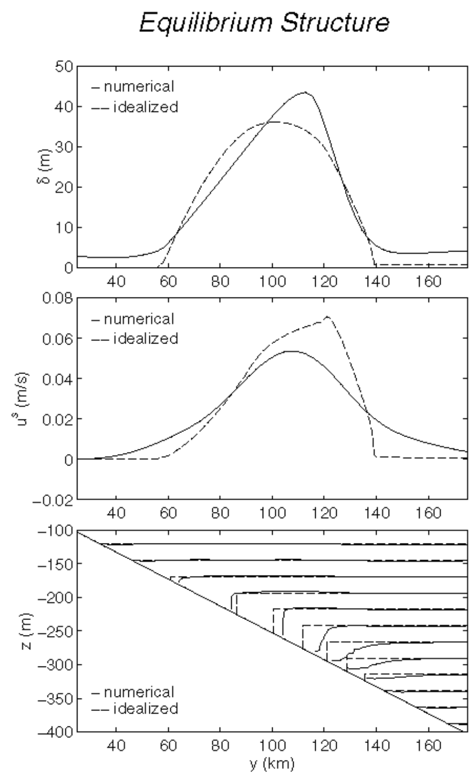

Figure 1: Equilibrium structure of the (upper) bottom boundary layer thickness, (middle) surface along-isobath velocity, and (lower) density field for both the numerical model (solid) and the idealized model (dashed).

We have made numerous numerical calculations to test the scalings predicted by the idealized model for the bottom boundary layer thickness, the interior velocity and the current width in the downstream equilibrium. Comparisons between the predicted scales and those found in the numerical results (Figure 2) support the basic scalings over the ranges of parameters examined.

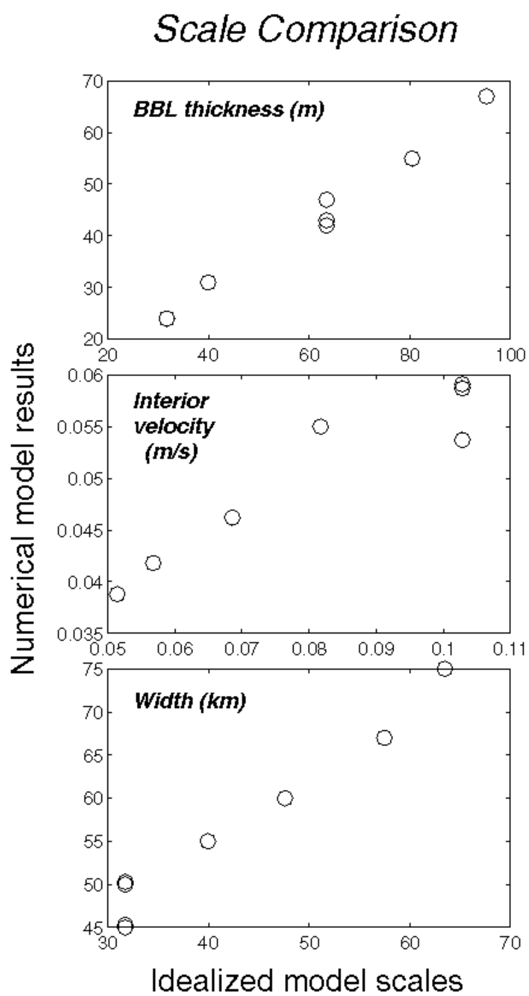

Figure 2: Comparison of equilibrium scales predicted by the idealized model and those estimated from the numerical model for (upper) bottom boundary layer thickness, (middle) interior along-isobath velocity, and (lower) current width. Each open circle represents a different numerical calculation. A linear dependence indicates that the numerical model results agree with the idealized model scalings.

Our analysis of existing current observations (in collaboration with J. Trowbridge) shows that fall and winter mean profiles from a mid-shelf site off northern California are similar from year to year, particularly near the bottom. Mean profiles at several different locations along the northern California shelf also have similar vertical structure. Analysis of observations from the STRESS program, which included density measurements and bottom stress estimates, indicate a reduction in bottom stress consistent with our idealized model. The vertical shear in the alongshelf flow near the bottom is not due to bottom stress, which is weak, but rather is in thermal wind balance with the cross-shelf density gradient (Figure 3). The vertical shear in the cross-shelf flow is also not frictional and is in thermal wind balance with an along-shelf density gradient. This is not consistent with our idealized model, but may be a consequence of complex bathymetry.

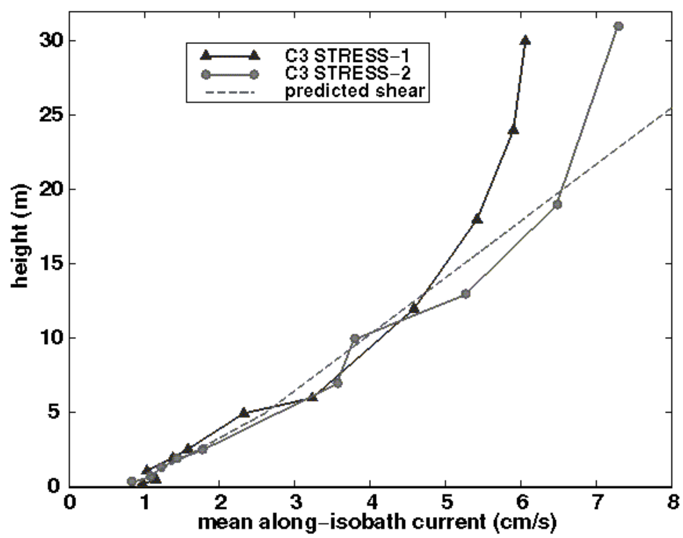

Figure 3: Mean along-isobath velocity observed at various heights above the bottom (symbol locations) over the California shelf at the 90 m isobath during the winters of STRESS-1 and STRESS-2. The dashed curve is the velocity shear predicted from the cross-isobath density gradient using the thermal-wind balance. Note the good agreement within about 15 m of the bottom.

IMPACT/APPLICATIONS

Our results suggest the important (and perhaps dominant) influence of the bottom boundary layer on ocean currents, even when the boundary layer is thin compared to the current depth. This may alter the way in which currents are modeled in large-scale models.

TRANSITIONS

There are no transitions at this point.

RELATED PROJECTS

We are beginning a collaboration with J. Trowbridge to examine the character of the bottom boundary layer and the interior flow during the Coastal Mixing and Optics (CMO) field program to determine whether the structure and dynamics are consistent with our idealized model.

We are collaborating with R. Pickart, who is examining the structure of the bottom boundary layer beneath the Deep Western Boundary Current.

REFERENCES

Chapman, D.C. and S.J. Lentz, 1997: Adjustment of stratified flow over a sloping bottom, Journal of Physical Oceanography, 27, 340-356.